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EXPERIMENTAL DETERMINATION OF BUCKLING STRENGTH OF STIFFENED PANELS

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ABSTRACT

In engineering application, the use of stiffened plates made of composite structures has increased over the last few decades due to its high efficiency in terms of high stiffness to low weight and high strength. Generally, the physical structure of stiffened plates is subjected to compressive in-plane loading and a continuous increase of these load results in buckling which in terms causes structural failure. Experimental work is carried on stiffened and un-stiffened plates with the composite materials have been carrying with a view to predicting the buckling load by fabricating it with glass fiber with epoxy resin by pattern molding technique. Analyses are performing to investigate the effect of strength on the stiffened panel using both isotropic material and fiber reinforced composite material on stiffeners

KEYWORDS: Composite Materials, Buckling Strength, Stiffened Panel, Z-Stiffener & J-Stiffener

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Original Article

INTRODUCTION

There are many types of failures in engineering structures. Some of them include creep, fatigue, alternate stresses, bending, buckling, etc. Buckling takes place in the columns, plates, shells, and other structures of regular or irregular geometry. The minimum load at which the equilibrium is disturbed is called as the critical buckling load. Thin -walled structure or plate- like elements (un-stiffened) are generally encountered in a ship, aircraft, marine, and bridge construction. In engineering structures, for structural efficiency and conservation of weight with no loss of strength, most of the thin- walled structures are stiffened. Because when thin walled or un-stiffened structure subjected to various types of load such as uniaxial compression, biaxial compression, pressure load, bending moment and shearing load, etc. result in buckling due to which structural failure of thin -walled or un-stiffened structure occurs. The common way to increase the buckling resistance of un-stiffened structure may be either to increase the thickness of the structure or by using stiffeners. The choice is in most cases based on the total economy that is the cost of increasing the web thickness of un-stiffened structure; result in a heavyweight product. On the other hand, reinforcing the thin- walled structure with lightweight stiffeners reduces the cost as well as the weight. Designers are most concerned about lightweight structural performance and efficiency. This means high -performance products need to be lightweight, yet strong enough to take harsh loading conditions [1]. So instead of increasing the thickness of un-stiffened structure for the prevention of buckling, use of a stiffener is the best method. Stiffener also called as stringer or girder, it is a type of beam, it can be placed in longitudinal or transverse direction and a variety of stiffeners can be fabricated over the plate such as flat bar, hat type, I-section, T-section

and angle section. The use of stiffened plate to make fuselage in the aerospace industry is shown in Figure 1.

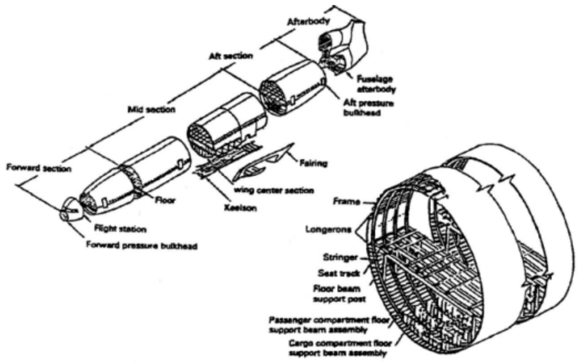
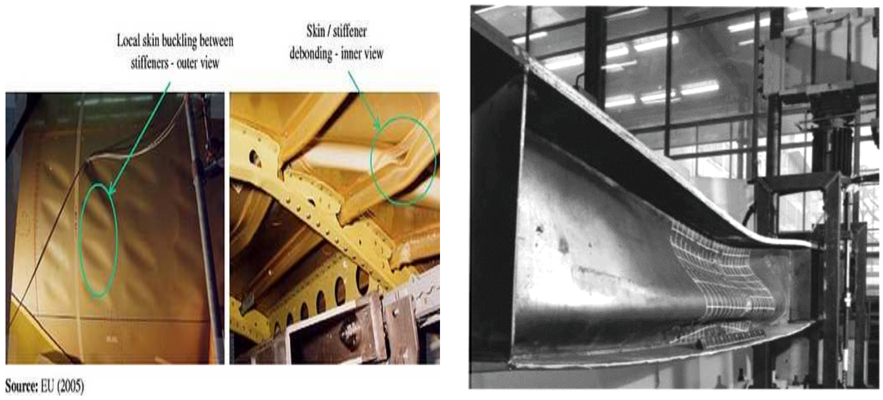


Figure 1: Aircraft Fuselage [2]

A stiffened structure consists of a large number of structural components such as skin, stringers, spars, ribs, and clips. For joining these elements together, it required mechanical fastening process. In homogeneous or conventional metallic material such fastening process, not so much costly, but there is the problem of fatigue and corrosion which needs expensive treatments and periodic inspections due to this at the beginning of 1960s the implementation of composite materials in stiffened structure makes it possible to overcome problems related to the metallic material. The use of advanced composite materials is increased in various structures such as in marine, aerospace and civil. The most vital difference between composite and metallic materials is to achieve the most effective mechanical properties such as strength, membrane, and bending stiffness, etc., by changing the layup configuration and a number of layers. Therefore, the laminated composite plates are considered as the basic modules, in high -performance boats, aircraft and many other complex structures, which require better durability, less specific weight, and excellent damage tolerance and are often subject to air-blast loading or underwater shock.

In aircraft and ship, the composite stiffened plate is usually subjected to in-plane biaxial or uniaxial compressive loading. This load acts in the middle plane of the plate called in-plane loading. When a structure is subjected to the low value of in-plane compressive loads, it remains stable and is in equilibrium condition. As the magnitude of these load increases continuously, however, the an equilibrium configuration of the structure is eventually changed and becomes unstable. The magnitude of the compressive load at which the structure becomes unstable is called the “critical buckling load” [3]. The composite stiffened plate is assembled with a multilayer unidirectional fiber lamina at different fiber orientation and different ply thickness. The discontinuity of material property through- thickness direction and interaction of ply material nonlinearity among the composite lamina result in complex deformation and failure of the structure. This situation is of composite stiffened plate concern in buckling and post -buckling [4]. Depending on the geometry, stiffness and boundary condition stiffened plate can exhibit a different mode of buckling, which might be local, global or mixed. The buckling of fuselage and web of the stiffener is shown in Figure 2 (a) and (b) respectively.



(a) **(b)**

Figure 2(a): Buckling in Fuselage (b) Buckling in Web of Stiffener

So, the elastic buckling and buckling strength analysis of the stiffened plates subject to the in-plane loading is very important in structural design and analysis [5]. But, the physical problems subjected to composites are more complex compared to isotropic material more difficult to quantify, understand and analyze. So, for analyzing the non-uniform geometry and material distribution over composite material under boundary and loading condition it requires the numerical analysis techniques such as the finite element method and other approximate methods [6]. There are many researchers has been performed on the buckling analysis related to the stiffened plate. In 1991 Yaqui [7] described the study of buckling behavior of laminated composite plates with a central cut-out that has been obtained by using the finite element method. In 2004 [5] Jameel studied the buckling behavior of an elastic plate with a circular hole.

Some researchers have studied the buckling behavior of composite plate with experimental. They have mostly investigated the effect of the cut-out on buckling load for composite laminate also effect of aspect ratio with a cut-out for different boundary condition and result verified with ANSYS,MSC., Patran/Nastran software[8]. Reddy et al. [9] investigated the non-dimensional buckling factor for three types of composite material with FEM.

Paulo et al.[10] carried a finite element analysis (FEA) to predict the complex mechanical behavior under heat affected zone of integrally stiffened panels when subjected to compressive loads, and particularly the ultimate load level, in the presence of elasto-plasticity, using ABAQUS for two types of stiffener such as trapezoidal and L-shaped. The result shows that the increase of the magnitude of the imperfections has a significant influence in the variation trend of the ultimate load levels, depending on the shape chosen for the imperfection. Vescovini and Bisagni [11] developed an analytical formula for the buckling and post- buckling analysis of composite flat and curved panels stiffened including composite and isotropic materials with omega stringers. Ezgi et al.[12] studied the nonlinear buckling behaviour of stiffened composite B−Al plates analyzed by means of finite element analysis (FEA) with simply supported thin plates under compressive loads are performed by employing shell mesh element SHELL91 (ANSYS) with four fibre configurations of the stiffened composite plates such as C1 [0º/90º/0º] plate+[(0º/90º)2]s stiffener, C2[0º/45º] plate+[(0º/45º)2]s stiffener , C3 [(0º/45º)2] plate + [(0º/45º)4] stiffener, C4 [(0º/30º/45º/60º)2]plate+ [(0º/30º/45º/60º)2]stiffener. The result shows that the nonlinear analysis of the C2 fiber configuration yields the safest critical buckling stress amongst C1, C2, C3 and C4 configurations also observed that stiffeners have a significant effect on the buckling behavior of plates under compressive loading and for various geometrical configurations. Broekel and Prusty [13] conducted an experiment to investigate the load–deflection bending response, load–ply failure relation, damage

progression before final failure, ultimate load of failure for each specimen, corresponding modes of failure, and effect of stiffeners on stiffened and un-stiffened composite panels under uniform transverse loading. The result shows that the effect of stiffeners is minimal and that the failure appears at the center of the long edge as a complete rupture. Graciano and Casanova [14] carried a numerical study to investigate the ultimate strength of I-girder webs subjected to the combined action of patch loading and bending. Results show that the coexistence of an in-plane bending moment reduces the ultimate strength of the stiffened plate girders subjected to patch loading. For large bending moments the patch loading resistance can be reduced more than 60%. The nonlinear computation is performed by using the commercial finite element software ANSYS v6.1. Pavlovcic et al. [15] examined the influence of varying positions and bending stiffness of one trapezoidal longitudinal stiffener on the panel shear resistance with geometric imperfection and its buckling behavior. From the result, it is concluded that the numerical simulations based on the test girder geometry, the measured initial geometric imperfections and elastic–plastic material characteristic from the tensile tests, demonstrate a very good agreement with the tests and stronger stiffeners forced the panel to buckle into local buckling shape of sub-panels, while the weaker stiffeners allow predominantly global buckling of the whole panel.

From the literature review, it was found that the good number of work has been done on buckling, post-buckling and ultimate strength of composite plate and stiffened composite plate subjected to shear, uniaxial or biaxial compressive,thermal load etc. But, they have used the method to finding the critical buckling load is the analytical, experimental which is time- consuming technique, few of them used the ABAQUS software based on finite element method and with ANSYS software very less work have been done. Very few literature have been found using the experimental investigation to determine stiffened plate strength. So research has been focused on mainly experimental to determine strength. For the present work, three different types of composite material such as Z and J shaped are selected for linear buckling analysis of un-stiffened and stiffened composite plate along with an empty plate. The selected material is used in theaerospace industry. A main goal of this work is to find the best, among the selected material by doing buckling analysis. Accordingly, the objective of the present study is

To investigate critical buckling load for composite plate under the

- Effect of a plate with no stiffener
- To investigate the critical buckling load for composite stiffened plate under the
- Effect of a plate with Z stiffener (two stiffeners are used)
- To investigate the buckling load for composite stiffened plate under the
- Effect of a plate with Z stiffener (three stiffeners are used)
- To investigate the buckling load for composite stiffened plate under the
- Effect of plate with J stiffener (two stiffeners are used)
- To investigate the buckling load for composite stiffened plate under the
- Effect of a plate with J stiffener (three stiffener are used)

METHODOLOGY AND MODELLING

Composite Specimen Preparation and Manufacturing

There are numerous methods for fabricating composite components. Some methods have been borrowed (injection molding, for example), but many were developed to meet specific design or manufacturing challenges.

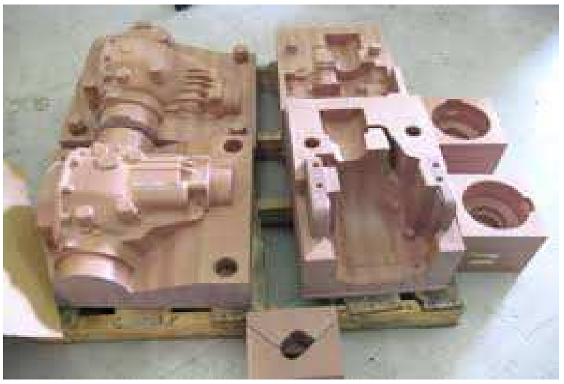


Figure 3: Molding Process

Selection of a method for a particular part, therefore, will depend on the materials, the part design.

To meet the wide range of needs which may be required in fabricating composites, the industry has evolved over a dozen separate manufacturing processes as well as a number of hybrid processes.

Each of these processes offers advantages and specific benefits which may apply to the fabricating of composites. Hand lay-up and spray-up are two basic molding processes. The hand lay-up process is the oldest, simplest, and most labor intense fabrication method. The process is most common in FRP marine construction.

STEPS followed in Fabrication Process

Step 01

Wet Layer up is the process we followed in fabricating both plates and stiffened panels.

Step 02

Wet lay-up involves the construction of a composite material through the integration of resin and reinforcement (fiber) components to form a matrix. The resin provides stiffness (keeps the fiber in position) and structure for the component ,while the fiber component provides the strength.

Step 03

In the hand lay-up method, liquid resin is placed along with reinforcement (woven glass fiber) against the finished surface of an open mould. Chemical reactions in the resin harden the material to a strong, lightweight product. The resin serves as the matrix of the reinforcing glass fibers', much as concrete acts as the matrix for steel reinforcing rods.

Preparation of Mold - Cleaning of the Mold

• To clean the mold, remove all left over epoxy and other materials after de-molding of the previously molded part.

Figure 4: Preparation of Moulds

HAND LAYUP PROCESS OF COMPOSITE PLATE MANUFACTURING

To manufacture the composites the following steps were followed.

- The weight of the fiber was noted down. Then the approximately 1/3rd mass of the hardener of epoxy was prepared for further use.
- A clean plastic sheet was taken and the mold releasing spray was sprayed on it. After that, a generous coating of the hardener mixture was coated on the sheet. A woven fiber sheet was taken and placed on top of the coating. After this again the coating of hardener was done. The second layer of fiber was placed and the process continued until the required thickness was obtained. The fiber was pressed with the help of rollers.
- Another plastic sheet was taken and the mold releasing spray was sprayed on it. The plastic sheet was placed on top of the fiber with hardener coating.
- The plate obtained was placed under weights for a period of 24 hours.
- After that, the plastic sheets were removed and the plates separated.

(a)

(b)

(c)

(d)

(e) **(f)**

Figure 5: (a), (b), (c), (d), (e), (f) - Fabrication Process

The reinforcing fibers are layered one on top of the other according to the lay-up schedule. The layers should be laid wet in wet; this means that consecutive layers are laid on top of the others before the epoxy has gelled to promote bonding between the layers

- Dab the canvas (using a brush) against the mold to impregnate it using the resin underneath.
- When there is no more resin underneath the layer, the resin should be applied. Do not keep the canvas too dry – impregnating the next layer will take longer than necessary; do not make it too wet – excessive resin is not removed easily!
- Apply the second layer, impregnating it by using the resin from the previous layer.
- When there is no more resin underneath the layer, apply new resin accordingly.
- Apply the rest of the layers as described above.

After allowing it to dry for 24 hours......

Figure 6: Fabricated Plates

EXPERIMENTAL RESULTS AND DISCUSSIONS

Buckling Test of Composite Specimens

The specimens were loaded in axial compression using a uniaxial tensile testing machine of 100- tonne capacity. It is shown in figure 7. The specimen was clamped at two ends and kept free at the other two ends.

Figure 7:UTM Machine

Two mild steel plates were arranged as fixture support in composite plates. Clamped boundary conditions were simulated along the top and bottom edges. For axial loading, the test specimens were placed between the two extremely stiff machine heads, of which the lower one was fixed during the test, whereas the upper head was moved downwards by servo -hydraulic cylinder.

For plate, placing two stiffeners at equidistance away from mid will gives 18.03 KN and for a plate, place three stiffeners will give the 43.1KN. From this results observed as the number of stiffeners increasing the strength of the plate also increasing.

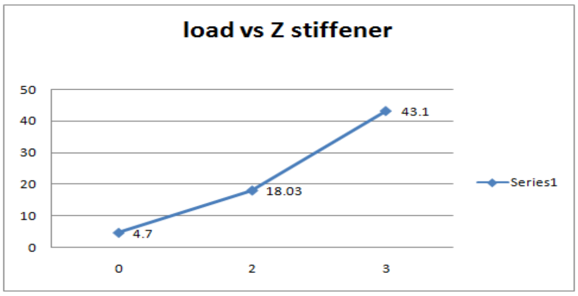


Figure 8: Load Vs Z Stiffener

For plate, placing two stiffeners at equidistance away from mid will gives 24.9 KN and for a plate, place three stiffeners will give the 30.2KN.

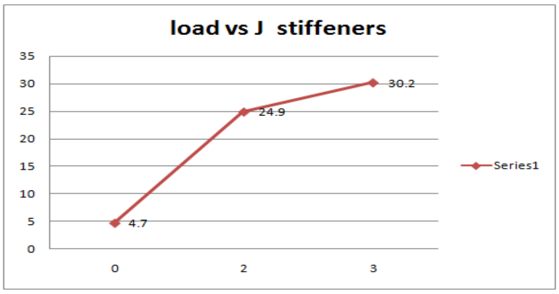


Figure 9: Load Vs J Stiffener

Table: Load data

Type of plate	Buckling load (k N)
Empty plate	4.7
Plate with Z stiffener- (2- stiffener)	18.03
Plate with J stiffener- (2- stiffener)	24.9
Plate with Z stiffener- (3- stiffener)	43.1
Plate with J stiffener- (3- stiffener)	30.2

For flat, thin plate buckling load is about 4.7KN. Whereas after adding stiffeners to the flat plate strength gas been found a minimum of four- fold increment. For plate with two Z - Stiffeners having 18.03 KN and J - Stiffener having 24.9. It shows for placing two stiffeners on the plate J type of stiffener having high strength. Were as placing three stiffeners Z shows high strength it may be due to the effect of high contact and surface area on the plate.

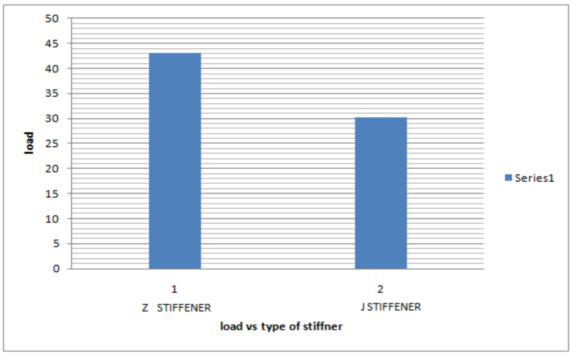


Figure 10: Load Vs Type of Stiffener

CONCLUSIONS

This study considers the buckling response of composite plates with clamped-free boundary conditions. From the experimental study, the following conclusions can be made.

- As we have seen through various experimental testing, buckling load is obtained from different types of the stiffened plate as well as the empty plate.
- Plate with Z type of stiffener is effective than J stiffener as we compare the buckling load for both types of stiffeners
- Plate with Three stiffeners has more buckling loads than two stiffener

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